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Quality parameters and oxidative stability of lamb during ageing

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Summary

The aim was to determine the quality parameters and oxidative stability of colour, lipids and proteins (formation of carbonyls) of vacuum packed lamb at a constant temperature of 2 °C ±1 °C up to 15 days post mortem. The suitability of lamb loin (longissimus lumborum) for ageing and optimal ageing period to obtain optimum sensory properties, especially tenderness and aroma was determined. A sample of 100 g lamb meat contains 23.48 g protein, 69.66 g water and 5.48 g fat. Lamb samples were the most tender after 11 days (both, sensory assessed and instrumentally measured – share force decreased by 61%) and had the best aroma after 15 days post mortem. In the meantime, the lamb became significantly brighter and more saturated (higher L*, a* and b* values), the content of secondary lipid oxidation products increased (1.7 times higher amount of malondialdehyde), and the content of protein carbonyls decreased to the initial value, despite an initial increase observed 11 days post mortem. We found that lamb loin is suitable piece for ageing; the optimal duration of ageing of loins is 15 days post mortem.

Keywords: lamb, ageing, physico-chemical parameters, oxidation products, protein carbonyls, sensory attributes

Introduction

We have deliberately aged beef, sheep, horse, deer and rabbit meat, more rarely veal and lamb. Poultry and pork are generally not aged, as the meat reaches tenderness less than 48 hours after slaughter. The basic purpose of meat ageing is to improve the tenderness, smell and taste or aroma of the meat. During the process of converting muscle into meat, biochemical changes occur in the muscles that directly affect the characteristics of the meat. Ageing of meat is a common name for many biochemical processes of enzymatic degradation of meat proteins, also known as proteolysis, and to a lesser extent the degradation of fats or lipolysis. Proteolysis is the predominant process and causes fragmentation or cleavage of the microstructure of muscle fibers, which improves the tenderness of the meat. The speed and extent of ageing depend on various factors such as animal species, age, diet and breed of the animal, as well as muscle type (Rant et al., 2019; Martínez-Cerezo et al., 2005).

Nowadays, interest of researchers in oxidation of meat is growing and over the last deca-

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de has focused on the oxidation of proteins. The reason for this is that meat is subjected to protein oxidation during ageing or storage, which leads to the formation of various oxidation products, including carbonyl groups. Through the formation of carbonyl and sulfhydryl groups, meat loses functional groups, i.e. intra- and/or inter-protein disulphide cross-links are formed. These strongly impair the functionality of muscle proteins and reduce the water holding capacity (Kim et al., 2010; Li et al., 2018). While the influence of lipid oxidation on food flavour and general food quality is well understood, the influence of protein oxidation on food quality is still poorly understood. The chemical changes that occur during protein oxidation are responsible for a number of biological modifications, such as protein solubility, fragmentation or aggregation of proteins. In view of these changes, it seems reasonable to assume that changes in meat protein caused by protein oxidation can affect the quality of the meat.

The aim of the study was to investigate quality parameters and the oxidation stability of proteins, lipids and colour change during storage of vacuum-packed lamb meat at a temperature of 2 °C ± 1 °C, while at the same time to investigate the suitability of lamb loin for ageing as well as its characteristics, tenderness and aroma.

Material and methods

Three carcasses or six lamb loins (LL, *longissimus lumborum*) were included in the experimental main part of the study. The lambs came from Slovenian breeding and rearing (the Jezersko - Solčava sheep breed, less than 12 months old, mean carcass weight, after slaughter 13 kg, reared for meat). The procedures of pre-slaughter, slaughter and first processing of the carcasses were performed according to established technology up to 24 hours *post mortem* (pm), LL muscle samples were taken 48 hours pm. During sampling, the LL muscle was cut from both halves of the carcasses (right and left half) and the pH was measured directly using a combined glass-gel spear electrode (Type 03, Testo pH electrode) with a thermometer (Type T, Testo penetration temperature probe) connected to a pH meter (Testo 230, Testo, Italy). The pH values ranged from 5.5 to 5.9 (normal muscle quality) in all tested muscles. Each muscle was then cut into two parts (in the middle of the muscle, perpendicular to the muscle fibres), so that four samples were taken from each carcass, making a total of 12 samples. The samples were weighed and vacuum packed in PVDC laminated bags (Cryovac). The ageing time (period) of each of the 12 samples was determined by random selection (within one animal). Ageing took place in a cooling chamber at a constant temperature of 2 °C ± 1 °C. The ageing periods were 2 (48 hours pm), 7, 11 and 15 days pm. After ageing, the samples were prepared for further analysis or frozen at -21 °C ± 1 °C after homogenisation.

On the second (as well as on the seventh, eleventh and fifteenth) day pm, a 3-4 cm thick slice was cut from the corresponding sample, temperature and pH value were measured directly using a pH meter (Testo 230, Testo, Italy). An instrumental colour analysis was performed on this slice on a fresh cut. The slice was then homogenised and used for immediate determination of the nutrient composition (water, fat, protein) and after freezing at -21 °C ± 1 °C, it was used for further chemical analysis (TBARs, protein carbonyls, fatty acid profile). The chemical analyses were performed in parallel; nutrient composition was measured in one and instrumental measurement of colour and texture in four parallels. The remaining piece of the raw sample was weighed, colour and marbling were sensory evaluated and the piece was vacuum packed. A one-hour moist heat treatment (at 75 °C) in a combi oven (Rational FRIMA (SSC61)) followed. The technique of *sous-vide* cooking or vacuum cooking was used. Sensory parameters (juiciness, tenderness, smell, aroma, and rancidity) were analysed on heat-treated samples and the texture (share force) was instrumentally measured after cooling the samples to room temperature (20 °C ± 1 °C).

Instrumental methods: The moisture, protein and fat content in the samples were determined with the Food ScanTM Analyser with self-calibration (FOSS, Denmark). pH values were measured directly with a combined glass-gel spear electrode (Type 03, Testo Pty Ltd, Australia) with a thermometer (Type T, TestoPty Ltd, Australia) connected to a pH meter (Testo 230, Testo Pty Ltd, Australia). The reading accuracy was 0.01 pH units. A CR-400 colorimeter (Konica Minolta Optics, Inc., Osaka, Japan; Illuminant C, 0° viewing angle) was used to determine the Commission Internationale de l'Eclairage (CIE; International Commission on Illumination) L^* (lightness), a^* (±, red to green) and b^* (±, yellow to blue) values on the surface of a 3-4 cm slice. A white ceramic tile

with the specifications Y = 84.6, x = 0.3176, y = 0.3245 was used to standardise the colorimeter. The CIE *L**, *a**, *b** colour values were measured at four different points on the surface of the sample. The instrumental analysis of the texture was performed with the TAXT plus texture analyser (Stable Micro Systems Ltd., Godalming, Surrey, UK) with a 50 kg load cell and at room temperature (20 °C). The cutting values (N) were measured in four parallels on heat-treated LL muscle slices (across the muscle fibres, 10 × 10 × 40 mm) as resistance of the sample to cutting by BLADE SET HDP/BS (Warner-Brazler - guillotine). The operating conditions were: blade speed 50 mm min–1, penetration into the muscle 9.4 mm.

Chemical analyses: Approximately 100 g of a representative sample were homogenised for 20 s with a Grindomix homogeniser (GM 200; Retch, Germany) at 5000-6000 rpm (ISO 3100-1, 1991). All chemical parameters were performed in parallel. The fatty acid composition was determined as described by Polak et al. (2008). The extent of lipid oxidation of the lamb samples was monitored by measuring the thiobarbituric acid reactive substances (TBARs) as described by Penko et al. (2015). A slightly modified (Rotar, 2019) spectrophotometric method by Soglia et al. (2016) was used to determine the protein carbonyl content. The absorbance was measured with a spectrophotometer (Agilent Technologies, Cary 8454 UV-Vis) at two wavelengths, 280 nm and 370 nm. The content of protein carbonyls was expressed in nmol/mg protein.

Sensory analysis: A panel of five qualified and experienced panellists in the field of meat products was used to assess the sensory qualities. The sensory evaluation of lamb samples was performed according to international standards (ISO 8589:2007, ISO 8586:2012). The analytical-descriptive test (Golob et al., 2005) was carried out by scoring the sensory according to a non-structured scale from 1 to 7 points, whereby a higher score indicated a stronger expression of a particular quality. An exception was typicality of the surface colour, which was evaluated by scoring on a structured scale from 1 to 4 to 7 (1-4-7). Here, a score of 4 points was considered optimal, with a score of 4.5 or higher indicating a stronger expression of a characteristic (too dark) and a score of 3.5 or lower indicating an insufficient expression of a characteristic (too light). Surface colour and marbling were estimated on the raw sample before heat treatment. The sensory profile of the samples was evaluated using seven descriptors grouped into four blocks: visual properties (surface colour and absence of marbling on the slice), texture (juiciness and tenderness), olfactory properties (odour) and gustatory properties (aroma and rancidity). For the sensory evaluation, the samples were cut as 2 mm thick slices, which were evaluated by the panellists. To neutralise the taste, the panel used the central dough of white bread.

Data analysis: The data were analysed for normal distributions (SAS/STAT). The differences by ageing periodes (2, 7, 11 and 15 day pm) were analysed using a general linear model procedure and the least squares mean tests (SAS/STAT), with a significance level of 0.05.

Results and discussion

Proximate composition

The nutrient composition in lamb was measured instrumentally on the total homogenate (combined residue of all samples on day 2 pm). On average, 100 g lamb meat contained 23.48 g protein, 69.66 g water and 5.48 g fat. Compared to the data from the Slovenian Nutrition Tables – Meat and Meat Products (Golob et al., 2006) and Rant et al. (2019), the results of our analysis differ slightly in water content (75.1 g/100 g and 74.35 g/100 g) and protein content (20.8 g/100 g and 20.29 g/100 g), while the fat content is comparable to the results of Rant et al. (2019) (1.6 g/100 g and 4.77 g/100 g).

From Table 1 we can summarize how the ageing period affected the weight loss after ageing and after heat treatment, as well as the pH value of lamb loin samples. The ageing period had a significant (P = 0.002) effect on the percentage weight loss; weight losses in 7-, 11- and 15 day pm samples were significantly higher (2-3.2 %) than in 2 day pm aged samples. They were visible as dark red or brown meat juice in the packaging unit. The ageing periods of the lamb had no statistically significant effect on the weight loss after heat treatment; the losses in aged samples ranged from 25.9 % to 28.5 %. Rant et al. (2019) report that ageing significantly affected weight loss after heat treatment of the LL muscle. In contrast, Abdullah and Qudsieh (2009) found that lamb aged for 7 days pm resulted in a significant reduction in weight loss after heat treatment in two muscles (*semitendinosus, longissimus*) of the Awassi breed.

In the present study, lamb samples aged

for 7 and 14 day pm had a lower (P=0.002) pH value when the samples were aged 2 days pm, the pH value decreased by 0.10 pH units. Rant et al. (2019) found that pH values of LL and GM (*gluteus medius*) muscles increased up to 15 days pm, but differences were significant only for the GM muscle. Abdullah and Qudsieh (2009) report that lamb aged 7 day pm had no effect on the pH values in the *semitendinosus*, *semimembranosus*, *biceps femoris* and *longissimus* muscles. In contrast, Yanar and Yetim (2001) found that the pH in the *longissimus dorsi* and *semimembranosus* muscles of adult sheep decreased significantly up to 7 days pm.

Table 1. Effect of lamb ageing period on weight loss during ageing and heat treatment and pH value

Parameter	Value of parameter according to days pm				P_A	SE	Mean across days pm
	2	7	11	15			
Weight loss (%) ageing	0.0^{a}	2.0^{b}	3.0^{b}	3.2^{b}	**	0.7	2.1
Weight loss (%) thermal treatment	25.9	27.1	28.1	28.5	Ns	3.4	27.4
pH value	5.79^{a}	5.60^{b}	5.71^{ab}	5.68^{b}	**	0.07	5.69

*P_A, statistical probability of ageing effect: *** P ≤0.001, statistically very highly significant; ** P ≤0.01, statistically highly significant; * P ≤0.05, statistically significant; Ns, P >0.05, statistically not significant. SE, standard error of mean. Data with different superscript letters within a row differ significantly (P <0.05, a-b differences between day of ageing).*

Determination of the optimal ageing period of lamb

The shear force required cutting the lamb sample decreased statistically significantly with prolonged ageing period (Table 2). On average, a force of 98.55 N was required to cut two day aged lamb sample and the force required to cut a 15 day aged sample decreased by 61 %. This data are in good agreement with Rant et al. (2019), who found that LL and GM muscles aged for 14 days had significantly lower share force (43.67 N) than those in fresh lamb (59.43 N), and Martínez-Cerezo et al. (2005), who found that 16-day maturation of LL muscle, from three different breeds of lambs with three different carcass weights significantly improved share force/ tenderness. Similarly, Abdullah and Qudsieh (2009) reported that 7-day ageing period significantly improved the tenderness of three lamb muscles (*biceps femoris, longissimus dorsi, semimembranosus*). Improvement in tenderness is as a result of

Table 2. Effect of lamb ageing period on instrumentally measured texture and sensory attributes

Parameter	Value of parameter according to days pm				P_A	SE	Mean across days pm
	2	7	11	15			
Instrumentally measured texture							
Colour^{ξ} (1-4-7)	4.0^{b}	4.0^{b}	4.1^{ab}	4.1^{a}	*	0.2	4.1
Marbliness^{ξ} (1-7)	1.7^{b}	1.6^{b}	1.5^{b}	2.1^{a}	***	0.4	1.8
Juiciness (1-7)	5.3^{bc}	5.3^{c}	5.7^{a}	5.5^{b}	***	0.3	5.4
Tendreness (1-7)	5.1^{c}	5.5^{b}	6.3^{a}	6.2^{a}	***	0.6	5.8
Smell (1-7)	6.0^{b}	5.8^{c}	6.2^{a}	6.3^{a}	***	0.3	6.1
Aroma (1-7)	6.0^{c}	6.1^{c}	6.3^{b}	6.7^{a}	***	0.3	6.3

*P_A, statistical probability of ageing effect: *** P ≤0.001, statistically very highly significant; ** P ≤0.01, statistically highly significant; * P ≤0.05, statistically significant; Ns, P >0.05, statistically not significant. SE, standard error of mean. Data with different superscript letters within a row differ significantly (P <0.05, a-c differences between day of ageing). ξ, raw samples measurement.*

muscle structure breakdown, which reduces the strength of myofibrils and facilitates the release of meat juice during chewing. Based on the instrumental texture analysis in present study can be concluded that the optimal ageing period of lamb is 11 days, when the best tenderness is achieved.

A more detailed effect of ageing period on the sensory properties of lamb meat is presented in Table 2. Colour and marbling were assessed on fresh cut samples, other sensory parameters were assessed on heat-treated samples.

After 7-day ageing period, tenderness (by 0.44) and aroma (by 0.11) improved significantly, while there were no statistically significant differences in other sensory parameters. After 11-day ageing period, juiciness (by 0.39), tenderness (by 1.19), smell (by 0.17) and aroma (by 0.33) improved significantly, and after 15-day ageing period, among other sensory parameters, also the colour (by 0.14) and marbling (by 0.39) improved significantly. The greatest changes during the ageing process are characterized by tenderness, which improved by 1.17 points after 15 day of ageing, and the aroma, which improved by 0.69 points. Based on the sensory analysis, we can conclude that the optimal ageing period of lamb is 11 days (when the best tenderness is achieved) or 15 days (in addition to tenderness, the best aroma is also achieved).

While tenderness is the most important factor determining the acceptance of veal (Domaradzki et al., 2017), aroma and tenderness are the most valued characteristics of lamb (Watkins et. al., 2013). One of the main reasons for consumer rejection of lamb is its distinctive aroma. At the same time, it is the aroma that convinces consumers to buy lamb and makes it more palatable than meat from other species (Schreurs et al., 2008). Martínez-Cerezo et al. (2005) found that lamb breed, carcass weight at slaughter and ageing period influenced the tenderness and juiciness. In their opinion, the improvement in tenderness is more influenced by the ageing time than by the breed or carcass slaughter weight.

We found a negative, statistically highly significant correlation between the instrumentally measured share force and the sensory evaluation tenderness ($r = -0.739$, $P < 0.001$). The shear force required to cut the lamb sample was the lowest on the eleventh day of ageing. The results of the sensory analysis are consistent with the results of texture measurement; the lamb muscle was the most tender after 11 days of ageing.

Oxidative stability of lamb during ageing

The oxidative stability of lamb during ageing was determined by instrumental colour measurement, TBARs and the protein carbonyl content (Table 3). In addition, the fatty acid profile was also presented.

In concussion, the colour of lamb LL muscle became lighter and more saturated during ageing; in meat aged for 15 days pm the L^*, a^* and b^* values increased significantly (2.06, 2.04 and 3.67 units). Rant et al. (2019) report that the 14-day ageing period had no effect on the colour values, which contradicts our results. Their results also differ from Tschirhart-Hoelscher et al. (2006), who reported a higher L^* value (not significant) and a lower a^* and b^* values in the LL lamb muscle aged for 7 days pm. Abdullah and Qudsieh (2009) observed a significant increase in a^* value on the *longissimus* muscle aged for 7 day pm, the two other colour values did not differ statistically. The colour of the meat is mainly determined by myoglobin, whose concentration in skeletal muscle may depend on its physiological activity, the type of muscle fibers in its structure (Mancini and Hunt, 2005). Myoglobin concentration is higher in muscles with slower oxidative fibers (Picard et al., 2002).

TBARs increased significantly during lamb ageing (Table 3), in meat aged for 15 days pm lipid oxidation parameter for 0.18 mg malondialdehyde/kg increased. There were also statistically significant differences between the individual ageing periods, namely between 7 and 15 days pm. The first significant increase in TBARs was seen after 7 days pm.

A higher TBAR means a higher degree of oxidation, but not always a change in sensory properties (Penko et al., 2015). An adequate TBAR is up to 0.70 mg malondialdehyde (MDA)/kg; values above 1 mg MDA/kg predict sensory perceived rancidity. In the present study, TBAR level increased significantly in meat aged for 15 pm (0.25 mg MDA/kg vs. 0.43 mg MDA/kg) which means that the range of oxidative reactions was so limited that rancidity is not yet sensory perceived. Rant et al. (2019) found that in LL lamb muscle aged for 14 days pm lipid peroxidation rate increased, but the differences were not statistically confirmed, which contradicts the results of our experiment. Ponnampalam et al. (2017) found that

Table 3. Effect of lamb ageing period on colour, lipid and protein oxidation parameters

Parameter	Value of parameter according to days pm				P_A	SE	Mean across days pm
	2	7	11	15			
Instrumentally measured texture							
*L**	39.63^{b}	40.52^{ab}	40.52^{ab}	41.69^{a}	*	1.48	40.59
*a**	18.15^{b}	19.52^{a}	19.65^{a}	20.19^{a}	***	1.08	19.38
*b**	5.15^{c}	4.87^{c}	6.74^{b}	8.82^{a}	***	0.96	6.39
Lipid oxidation parameter (mg malondialdehyde/kg)							
TBARs$^{\xi}$	0.25^{c}	0.31^{b}	0.3^{b}	0.43^{a}	***	0.04	0.32
Fatty acid composition (g/100 g total FA)							
SFAs	49.97^{a}	47.58^{b}	46.71^{b}	46.99^{b}	**	1.44	47.81
MUFAs	43.79	38.38	40.42	40.68	Ns	4.27	40.82
PUFAs	6.24^{b}	14.03^{a}	12.88^{a}	12.33^{ab}	Ns	5.24	11.37
trans	3.10	3.65	3.43	3.60	Ns	0.76	3.44
AI	0.95	0.95	0.89	0.92	Ns	0.1	0.93
P/S	0.13^{b}	0.30^{a}	0.28^{a}	0.27^{ab}	Ns	0.12	0.24
n-3	2.33^{b}	7.07^{a}	6.25^{a}	5.96^{ab}	Ns	3.07	5.4
n-6	3.91^{b}	6.96^{a}	6.63^{ab}	6.38^{ab}	Ns	2.2	5.97
n-6/n-3	1.67^{a}	1.11^{b}	1.18^{b}	1.18^{b}	*	0.29	1.29
Protein oxidation parameter (nmol/mg proteins)							
protein carbonyls	3.95^{b}	3.84^{b}	4.69^{a}	3.88^{b}	0.023	0.5	4.08

*P_A, statistical probability of ageing effect: *** P ≤0.001, statistically very highly significant; ** P ≤0.01, statistically highly significant; * P ≤0.05, statistically significant; Ns, P >0.05, statistically not significant. SE, standard error of mean. Data with different superscript letters within a row differ significantly (P <0.05, a-c differences between day of ageing). ξ, raw samples measurement. SFAs, saturared fatty acids. MUFAs, monounsaturated fatty acids. PUFAs, polyunsaturated fatty acids.*

peroxidation depends on the type of diet. One of the most commonly used antioxidants in animal nutrition is vitamin E, which inhibits lipid oxidation and provides colour stability (López-Bote et al., 2001). Due to the lack of pasture in the dry Mediterranean climate, lambs are often kept indoors and fed on concentrated feed and straw. Numerous studies have shown that grazing lambs have higher levels of vitamin E in their muscles than lambs fed with highly concentrated feed (Jose et al., 2008). Ripoll et al. (2013) found that the oxidation rate increased after 7 days of lamb muscle LL ageing, although it varied depending on the feed composition and the degree of addition of α-tocopherol to the animal feed. Ponnampalam et al. (2017) also found a significant increase in lipid oxidation rate in 60-day aged lamb. Feeding lambs with α-tocopherol concentration during the last 10 days before slaughter or grazing of alfalfa greatly reduces the lipid oxidation rate of the meat. The type of packaging is also an important factor. Lipid oxidation values of more than 1 mg MDA/kg muscle were confirmed after 5 days storage in a modified atmosphere that increases oxidation (Camo et al., 2008). Other studies have also reported higher TBAR levels in meat packed in oxygen packs (Delles and Xiong, 2014; Zakrys et al., 2008).

After 15 days of ageing, the proportion of saturated fatty acids (SFA) in lamb decreased significantly and the *n-6/n-3* ratio improved (Table 3), mainly due to *n-3* fatty acids such as docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA). Rant et al. (2019) found that the ageing of lamb LL and GM muscles does not affect the fatty acid composition. The proportion of long-chain unsaturated fatty acids (LC PUFA) with more than two unsaturated bonds, which are more exposed to oxidation during ageing, increased (not shown in the Tables) and consequently TBA increased significantly. As reported Yang et al. (2002), even small changes in the LC PUFA concentration can significantly affect the oxidative stability of meat.

The protein carbonyl content in the lamb aged for 15 days pm slightly decreased (3.95 vs. 3.88 nmol/mg protein). The content was the highest in samples aged for 11 days pm (4.69 nmol/mg protein). Santé-Lhoutellier et al. (2008) investigated the effect of lamb diet on the protein carbonyl content during storage. The initial value of protein carbonyls, 2 nmol/mg protein, in meat aged in permeable packaging 7 days pm increased significantly, namely 13 % in the grazing group and 31.4 % in the concentrate group. In addition, a significant correlation was observed between the amount of vitamin E and the content of carbonyl groups after 7 days of storage, confirming the protective effect of vitamin E on protein oxidation. Similar results were obtained by Petron et al. (2007), who found that the protein carbonyl content is significantly increased during storage of lamb in the refrigerator.

In this study a significant increase in protein carbonyl content confirmed in lamb aged for 11 days pm. It is difficult to explain the strong decrease in carbonyl content during the next five days of ageing to a lower level than during the initial ageing period. What happens with the other parameters in meat aged for 11 and 15 days pm? The pH value decreased by 0.02 units and the TBARs increased by 0.13 mg MDA/kg. In the literature these parameters are mentioned as important carboxylation factors. Lower pH and lipid oxidation are associated with the oxidation of meat proteins (Estévez, 2011; Mercier et al., 1998), so it is not entirely clear what is the cause of decrease in protein carbonyl content during this period. The reduced (not significant) protein carbonyl content in meat aged for 15 days pm can be attributed to several factors. Impermeable packaging reduces the level of oxidation (Estévez, 2011). Protein oxidation, measured as loss of free thiol groups, was 20-80 % higher in pork in oxygen rich packaging units. An increase in lipid oxidation by-products has shown that molecular oxygen increases oxidative stress (Bao and Ertbjerg, 2015).

The total protein carbonyl content in a variety of animal tissues is about 1-2 nmol/mg protein (Requena et al., 2001). For a realistic evaluation of the protein oxidation rate in lamb, it should be noted that freezing of the meat samples before analysis can affect the level of protein carbonyls formation. Studies have shown that proteins are subject to the formation of carbonyl compounds during storage of frozen meat, namely in pork (Estévez et al., 2011; Xia et al., 2009), beef (Popova et al., 2009) and poultry (Rababah et al., 2010; Soyer et al., 2010). Opposite, Kuhar (2020) found that the content of protein carbonyls in 7- and 14-days frozen veal was significantly lower compared to the fresh samples. So, data from the literature on protein carbonyls in frozen and unfrozen samples are contradictory and deserve more detailed observation on lamb in future.

Interestingly, in this study the lamb aged for 11 days pm was tenderer, when at the same time the protein carbonyl content was significantly highest. In general, however, it could neither confirm the relationship between protein carbonyl content and instrument measured tenderness ($r = 0.342$, $P = 0.418$) nor the relationship between protein carbonyl content and sensory evaluated tenderness ($r = 0.173$, $P < 0.001$). In contrast, Rowe et al. (2004) and Zakrys et al. (2009) confirmed a relationship between protein oxidation and reduced muscle tenderness in beef. The protein oxidation and texture changes were reported in various meat products such as liver pâtés (Estévez and Cava, 2004) and emulsified cooked pies (Ganhão et al., 2010). However, the relationship between protein carbonyls and tenderness of meat is not entirely clear.

Conclusion

The sensory profile of lamb loins aged for 15 days pm greatly improved; the best tenderness was achieved after 11 days, the best aroma after 15 days, and juiciness did not improve. In the meantime, the colour of lamb loins became brighter and more saturated (instrumentally measured colour parameters increased). From the determination of lipid oxidation products, it can be concluded that TBARs increased 1.7-fold during this period, the content of saturated fatty acids decreased and the ratio n-6/n-3 improved. The protein carbonyls content was maintained at the level of 2nd day pm, despite an increase after ageing for 11 days pm. Further investigation is needed to support that ageing of lamb meat under appropriate retail conditions might benefit lipid and protein oxidation parameters. For producers and consumers, the supply of aged lamb on the market represents an interesting market niche or an interesting choice from a nutritional and gastronomic point of view.

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Značajke kvalitete i oksidacijska stabilnost janjetine tijekom zrenja

Sažetak

Cilj rada bio je odrediti značajke kvalitete i oksidacijsku stabilnost boje, lipida te bjelančevina (stvaranje karbonila) janjetine pakirane u vakuumu, starosti do 15 dana nakon klanja, pri stalnoj temperaturi od 2 °C ± 1 °C. Utvrđivana je primjerenost janjećeg filea (*longissimus lumborum*) za zrenje te optimalno vrijeme zrenja, a kojima se postižu najbolja senzorička svojstva, posebice mekoća i aroma. Uzorak od 100 g janjetine sadrži 23,48 g bjelančevina, 69,66 g vode i 5,48 g masti. Uzorci janjetine su bili najmekši 11 dana nakon klanja (senzorička procjena i mekoća utvrđena instrumentima – udio sile smanjen je za 61 %), pri čemu je najbolja aroma utvrđena 15 dana nakon klanja. Janjetina je starenjem postala značajno svjetlija i zasićenija (veće vrijednosti L*, a* i b*), povećao se sadržaj sekundarnih produkata oksidacije

lipida (1,7 puta veća količina malondialdehida), dok se sadržaj proteinskih karbonila, po početnom povećanju zabilježenom 11 dana nakon klanja, smanjio na početnu vrijednost. U svrhu objektivnije procjene brzine oksidacije bjelančevina u janjetini, valja napomenuti da je sedmodnevno smrzavanje mesa prije analize značajno smanjilo sadržaj proteinskih karbonila (32 %). Utvrđeno je da je janjeći file primjeren za produženo zrenje, pri čemu optimalno trajanje zrenja filea iznosi 15 dana nakon klanja.

Key words: : janjetina, produženo zrenje, fizikalno-kemijske značajke, produkti oksidacije, proteinski karbonili, senzorička svojstva

Qualitätsparameter und oxidative Stabilität von Lammfleisch während der Reifung

Zusammenfassung

Das Ziel der Arbeit war es, die Qualitätsparameter und die oxidative Stabilität von Farbe, Lipiden und Proteinen (Bildung von Carbonylen) von vakuumverpacktem Lammfleisch bei einer konstanten Temperatur von 2 °C ±1 °C bis zu 15 Tage nach der Schlachtung zu bestimmen. Es wurde die Eignung der Lammlende (*longissimus lumborum*) für die Reifung und die optimale Reifezeit zur Erzielung optimaler sensorischer Eigenschaften, insbesondere der Zartheit und des Aromas bestimmt. Eine Probe von 100 g Lammfleisch enthält 23,48 g Eiweiß, 69,66 g Wasser und 5,48 g Fett. Die Lammfleischproben waren nach 11 Tagen am zartesten (sowohl sensorisch beurteilt als auch instrumentell gemessen - der Anteil nahm um 61% ab) und hatten nach 15 Tagen nach dem Schlachten das beste Aroma. Mit der Reifung wurde das Lammfleisch deutlich heller und gesättigter (höhere L*-, a*- und b*-Werte), der Gehalt an sekundären Lipidoxidationsprodukten stieg an (1,7-mal höhere Menge an Malondialdehyd), und der Gehalt an Proteincarbonylen sank auf den Ausgangswert, trotz eines 11 Tage nach der Schlachtung beobachteten anfänglichen Anstiegs. Für eine realistische Bewertung der Proteinoxidationsrate bei Lammfleisch ist zu beachten, dass ein 7-tägiges Einfrieren des Fleisches vor der Analyse den Proteincarbonylgehalt signifikant reduzierte (32%). Es wurde herausgefunden, dass die Lammlende ein für die Reifung geeignetes Stück ist; die optimale Dauer der Reifung der Lenden beträgt 15 Tage nach dem Schlachten.

Schlüsselwörter: : Lamm, Reifung, physikalisch-chemische Parameter, Oxidationsprodukte, Proteincarbonyle, sensorische Eigenschaften

Los parámetros de calidad y estabilidad oxidativa del cordero durante la crianza

Resumen

El fin de este estudio fue determinar los parámetros de calidad y estabilidad oxidativa del color, de los lípidos y proteínas (formación de carbonilo) de cordero envasado al vacío hasta 15 días después del sacrificio, a una temperatura constante de 2 ° C ± 1 ° C. Se determinó la idoneidad del filete de cordero (*longissimus lumborum*) para la crianza y el período óptimo de crianza para obtener las mejores propiedades sensoriales, especialmente ternura y aroma. Una muestra de 100 g de carne de cordero contiene 23,48 g de proteína, 69,66 g de agua y 5,48 g de grasa. Las muestras de cordero tuvieron la mayor ternura 11 días después del sacrificio (tanto evaluadas sensorialmente como medidas instrumentalmente; la proporción de fuerza se redujo en un 61%), con el mejor aroma determinado 15 días después del sacrificio. El cordero se volvió significativamente más brillante y saturado con la edad (valores más altos de L *, a * yb *), el contenido de productos secundarios de oxidación de lípidos aumentó (1,7 veces mayor cantidad de malondialdehído), mientras que el contenido de proteína carbonilo, luego del aumento inicial registrado 11 días después del sacrificio, se ha reducido al valor inicial. Para evaluar de manera más objetiva la tasa de oxidación de proteínas en el cordero, debe tenerse en cuenta que con la congelación de

la carne durante siete días antes del análisis se redujo significativamente el contenido de proteína de los carbonilos de proteína (32%). Fue determinado que el filete de cordero era apto para el envejecimiento, siendo la duración óptima del envejecimiento del filete 15 días después del sacrificio.

Palabras claves: cordero, envejecimiento, parámetros fisicoquímicos, productos de oxidación, carbonilos de proteínas, atributos sensoriales

Impatto del tempo sulle caratteristiche di qualità e stabilità ossidativa della carne d'agnello

Riassunto

Il presente studio aveva lo scopo di determinare le caratteristiche concernenti la qualità e la stabilità ossidativa del colore, dei grassi e delle proteine (formazione di carbonile) della carne d'agnello confezionata sottovuoto a 15 giorni dalla sua macellazione a una temperatura costante di 2 °C ± 1 °C. È stata accertata l'idoneità del filetto d'agnello (longissimus lumborum) all'invecchiamento e la sua durata ottimale cui si attribuiscono i migliori risultati in termini di proprietà sensoriali, tenerezza e aroma. Il campione di 100 g di carne d'agnello contiene 23,48 g di proteine, 69,66 g d'acqua e 5,48 g di grassi. I campioni di carne d'agnello col maggior grado di tenerezza si sono dimostrati quelli dopo 11 giorni dalla macellazione (valutato sensorialmente e misurato con gli strumenti – sforzo di taglio ridotto del 61%), mentre il miglior aroma è risultato quello della carne a 15 giorni dalla macellazione. La carne d'agnello, col passare del tempo, è diventata più chiara e opaca (valori L*, a* e b* più alti), è aumentato il contenuto dei prodotti secondari dell'ossidazione dei lipidi (la quantità di malondialdeide è risultata 1,7 volte superiore), mentre il contenuto di carbonile proteico, dopo un iniziale incremento a 11 giorni dalla macellazione, s'è ridotto al valore iniziale. Ai fini di una valutazione maggiormente aggettiva della velocità di ossidazione delle proteine nella carne d'agnello, va detto che, dopo sette giorni di congelatore prima dell'analisi, il contenuto di carbonili proteici nella carne s'è sensibilmente ridotto (32%). È stato accertato che il filetto d'agnello è idoneo all'invecchiamento, laddove la sua durata ottimale è di 15 giorni dopo la macellazione

Parole chiave: carne d'agnello, caratteristiche fisico-chimiche, prodotti dell'ossidazione, carbonili proteici, proprietà sensoriali